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iTREE: Intelligent Traffic and Resource Elastic Energy Scheme for Cloud-RAN using Bin Packing

Tshiamo Sigwele, Prashant Pillai, Yim Fun Hu
School of Electrical Engineering and Computer Science,
Faculty of Engineering and Informatics

University of Bradford, Bradford, United Kingdom
t.sigwele@bradford.ac.uk, p.pillai@bradford.ac.uk, y.f.hu@bradford.ac.uk

Abstract—By 2020, next generation (5G) cellular networks are expected to support a 1000 fold traffic increase. To meet such traffic demands, Base Station (BS) densification through small cells are deployed. However, BSs are costly and consume over half of the cellular network energy. Meanwhile, Cloud Radio Access Networks (C-RAN) has been proposed as an energy efficient architecture that leverage cloud computing technology where baseband processing is performed in the cloud. With such an arrangement, more energy gains can be acquired through statistical multiplexing by reducing the number of BBUs used. This paper proposes a green Intelligent Traffic and Resource Elastic Energy (iTREE) scheme for C-RAN. In iTREE, BBUs are reduced by matching the right amount of baseband processing with traffic load. This is a bin packing problem where items (BS aggregate traffic) are to be packed into bins (BBUs) such that the number of bins used are minimized. Idle BBUs can then be switched off to save energy. Simulation results show that iTREE can reduce BBUs by up to 97% during off peak and 66% at peak times with RAN power reductions of up to 27% and 18% respectively compared with conventional deployments.

Keywords—Cloud RAN; Cloud Computing; BBU Reduction; Green Energy; Pooling Gain.

I. INTRODUCTION

According to Huawei Technologies [1], Fifth Generation (5G) cellular networks will experience a thousand-fold increase in data traffic with over 100 billion connected devices by 2020. Such surge in traffic will be from smartphones, tablets, machine-machine connections and the Internet of Things (IoT). In order to support this skyrocketing traffic demand, smaller Base Stations (BS) with reduced cell size are deployed to increase capacity using spatial frequency reuse. However, this densification of BSs increases interference that can significantly degrade Quality of Service (QoS). Additionally, BSs consume the largest fraction of energy in cellular networks [2]. This contributes to the mobile network's Operating Expenditure (OPEX) and causes large amounts of CO₂ emissions.

A typical Long Term Evolution (LTE) BS that can be generalised to all BS types is shown in Fig. 1 [3]. The BS comprises of main power supply, cooling, Direct Current Converter (DC-DC), digital Baseband Unit (BBU), Radio Frequency (RF) transceiver, Power Amplifier (PA) and Antenna Interface (AI). Within each BS, a large amount of power is consumed by the PA and BBU as they become many.

Due to gradual shrinking of cell size and the growing complexity of signal processing, the energy consumption of

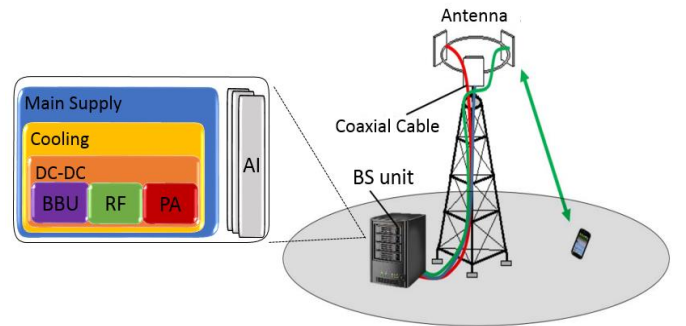


Fig. 1. Typical LTE BS

BBU implementation is getting more and more dominant in small cells [3]. Therefore, it is crucial to optimize energy efficient BBUs. A lot of energy efficient schemes for wireless systems have been implemented; offloading traffic to neighbouring BSs then completely turning off the BS during low traffic[4]; Discontinuous Transmission (DTX) where a BS is temporally switched off without offloading [5]; cell zooming; using renewable energy sources [6]. However, research on energy efficient schemes for cloud BSs in centralised RANs is ignored.

BSs have been preconfigured to provide peak capacities to reduce outages. Nevertheless, traffic is rarely at its peak in practical scenarios, traffic load in a cellular network changes gradually in a time-geometry pattern called the “Tidal Effect” which is the fluctuation of traffic load in the BS due to the dramatic subscriber density increase in both business and residential areas. However, current BS processing capacity is only being used for its own coverage rather than being shared in a large geographical area. Therefore during the night BSs in residential areas are over-subscribed while BSs in business areas stay idle while still consuming a lot of power whereas they can be switched off. It is imperative to solve this problem and free up the processing capacity and save energy.

Cloud Radio Access Networks (C-RAN) was proposed as an energy efficient architecture that leverage cloud computing technology [2]. C-RAN comprise of three parts; Remote Radio Head (RRH) which performs lower layer analogue RF functions; BBU for digital signal processing; and fronthaul connection between BBU and RRH. In C-RAN, digital

baseband processing of multiple distributed RRH is performed in the BS-Cloud and dynamically provisioned according to traffic needs. Furthermore, more energy savings can be gained from reduced air conditioning cost and reduced equipment room size. Instead of conventional peak power provisioning during low traffic times, minimum BBUs can be highly utilized to serve such low traffic.

This paper proposes a green Intelligent Traffic and Resource Elastic Energy (iTREE) scheme for C-RAN. This is an extension of the previous work in [7] where BBUs were consolidated in a BS-Cloud to improve utilization of the BSs and blocking probability of call requests. The work is extended by the following contributions:

- Devising an algorithm for reducing the number of BBUs in C-RAN by using a one to many mapping of BBU to RRH on an open (SDR) software defined radio information technology (IT) platform depending on traffic demands.
- Implementing a power model for C-RAN. In iTREE, baseband processing is dynamically allocated to RRHs on demand according to traffic needs. One BBU can serve multiple RRHs. Idle BBUs can then be switched off.

Simulation results show that iTREE can reduce BBUs by up to 97% during off peak and 66% at peak times with network power reductions of up to 27% and 18% respectively compared with conventional deployments.

The rest of this paper is organized as follows. The C-RAN architecture that is adopted in this paper is presented in Section II. Related work will be presented and analysed in section III. The proposed iTREE scheme is described in Section IV. Section V presents the simulation and the obtained performance results. Finally, conclusion and future works are presented in Section VI.

II. C-RAN: ARCHITECTURE

C-RAN was first introduced by China Mobile in 2010 with the “C” standing for centralised, collaborative, cooperative and clean/green [2]. Also in the same year, IBM [8] proposed a similar architecture to C-RAN called Wireless Network Cloud (WNC). The C-RAN architecture adopted in this paper is shown in Fig. 2. BBUs are decoupled from the BS and consolidated in the BS-Cloud leaving only the RF RRH in the cell sites. High bandwidth fibre links are then used to link the distributed RRHs to the BS-Cloud. The BBU performs digital baseband processing functions such as Physical (PHY) and Media Access Control (MAC) layer. The BS-Cloud is deployed on open IT architectures using SDR technology. SDR involves the implementation of all wireless baseband processing in software [9]. The target benefits of such a C-RAN architecture are:

- Any RRH traffic load can be processed on any BBU
- A single BBU can process multiple RRH baseband signals simultaneously due to SDR technology.
- Easy traffic offload from one BS to another.
- Reduction in air conditioning and other onsite power-consuming equipment.

The major disadvantage of C-RAN is that the BBU-RRH link has high bandwidth and low latency requirements due to the transmission of digital Inphase/Quadrature (IQ) signals. Fibre optic cables are the suitable fronthaul candidates but are usually expensive.

III. RELATED WORK

Several researchers have focused on improving energy efficiency of cellular networks. The benefits of energy efficient RANs are mainly to lower OPEX and the reduction in the amount of CO₂ emission. There are several solutions towards green BS such as improving BS hardware design, completely turning off the BS during low traffic [4], Discontinuous Transmission (DTX) where BS is temporally switched off without offloading traffic [5], cell zooming or changing cell size and also using renewable energy sources. However, research on energy efficient cloud BSs is largely ignored. This paper will target energy efficiency in C-RAN at the BS-Cloud.

The authors in [10] developed a BBU pool testbed using virtualization technology and GNU radio platform on general purpose processors. The BBUs are dynamically provisioned according to traffic load. However, the paper fails to show how the number of BBUs are reduced with dynamic traffic load. Also, Linux Operating System (OS) assisted virtualization is used which add more delays and jitter when performing baseband processing on virtual BSs. The authors in [11] proposed a BBU-RRH switching scheme for C-RAN that dynamically allocates BBUs to RRHs based on the imbalance of subscribers in office/residential areas. A set upper limit of BBU utilization is defined to avoid overloading of the BBU. Even though [11] reduces the number of BBUs required, the model performs poorly during high traffic loads consuming a lot of power since more BBUs are allocated to meet traffic demands.

In [12], the authors proposed an analytical energy model of a computational-resource-aware Virtual-BS (VBS) in a cloud-based cellular network architecture. The author considers the energy-delay trade-offs of a VBS considering BS sleeping mode in general IT platforms. The paper does not show how the energy savings of the VBS model scales with traffic load. L. Jingchu *et al.* in [13] presents a mathematical model to quantify the statistical multiplexing gain of pooling VBS. The author uses a multi-dimensional Markov model to evaluate pooling gain considering both compute and radio resources. Nevertheless, the author have not considered power consumption in the BS-Cloud. S. Namba *et al.* in [14] proposes a network architecture called Colony-RAN due to its ability to flexibly change cell layout by changing the connections of BBUs and RRHs in respect to traffic demand however, the proposed method has frequent reselections of RRH to BBU and also the BBU-RRH switching scheme is not explained. In [15], L. Cheng *et al.* developed an OFDMA-based C-RAN test-bed with a reconfigurable backhaul that allows 4BBUs to connect flexibly with 4 RHHs using radio-over-fiber technology. The backhaul architecture allows the

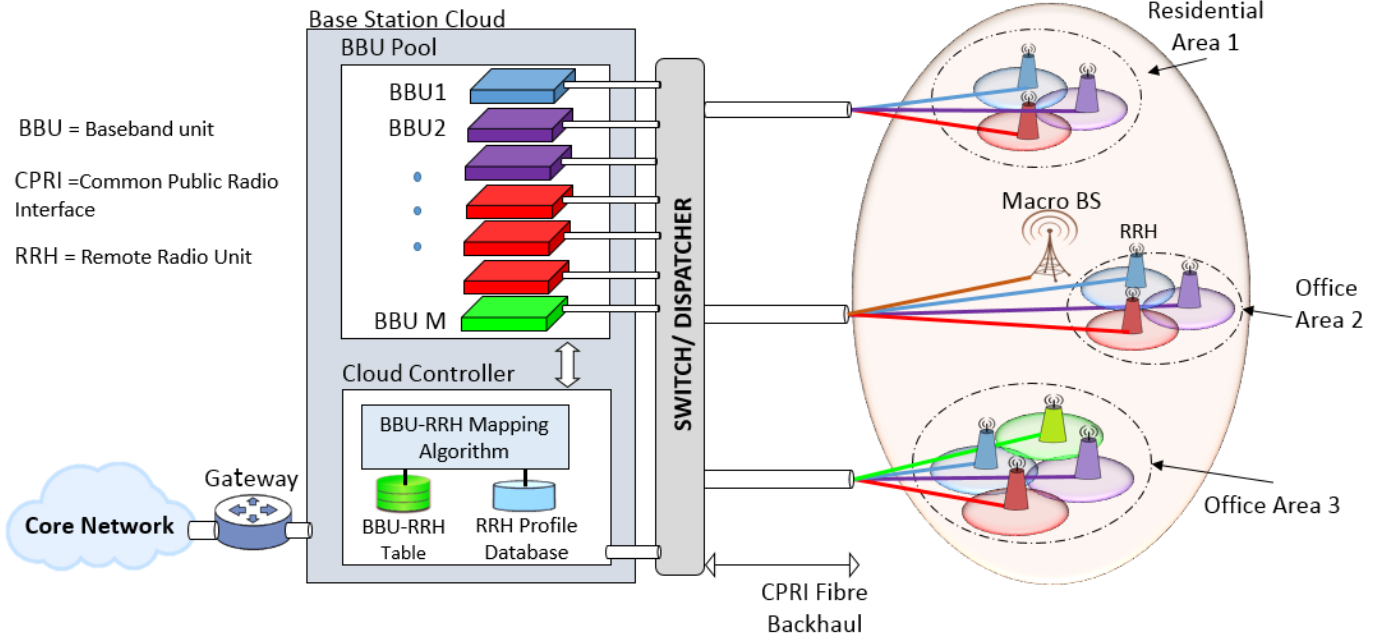


Fig. 2. Cloud RAN architecture.

mapping between BBUs and RRHs to be flexible and changed dynamically to reduce energy consumption in the BBU pool. However, the paper assumes static user traffic whereas in reality BS traffic is dynamic.

C. Wang *et al.* in [16] implemented an LTE testbed with virtualised BBU boards that contain VBSs. VBS live migration technology is used to enable multiple VBSs to be consolidated onto a single BBU board and reduces the power consumption of the BBU pool during low traffic times. However, the proposed solution for VBS live migration is unsuitable for real-time baseband processing since it introduces service interruption time of tens of milliseconds. The authors in [17] evaluate the energy and cost savings in mobile C-RAN by pooling BBU processing. The authors use the mobile traffic forecast for year 2017 and an OPNET Modeller and claim to reduce user data signal processing resources 4 times; however, the potential energy saving is not explained in detail.

IV. PROPOSED iTREE SCHEME

A. iTREE BBU-RRH Bin Packing Algorithm

The proposed iTREE system model structure is shown in Fig. 3. This model is the continuation of our previous work in [7]. The system model is defined by set R of available RRHs. Hence the set $R = [RRH_j; j=1, 2, \dots, N]$, where N is the maximum number of available RRHs. The network is served by a set of BBUs denoted by $B = [BBU_i; i=1, 2, \dots, M]$ where M is the number of BBUs serving N RRHs. This is a bin packing problem where N items (RRH resource demand) are to be packed into M bins (BBUs) such that the number of bins used are minimised. The demand for RRH baseband resources

is denoted $\delta_j^{RRH} \in [0, 1]$ corresponding to the traffic load within the RRH. Every single BBU has baseband resource utilization $\rho_i^{BBU} \in [0, 1]$. The cloud controller contains the mapping algorithm which is defined by a BBU-RRH connection matrix D of size M by N defined as $D = [d_{ij}]_{M \times N}$. If $d_{ij} = 1$, it means RRH_j is served by BBU_i , if $d_{ij} = 0$ then there is no connection association between RRH_j and BBU_i . The RRH traffic profile keeps track of traffic loads in the RRH. The BBU profile keeps track of the BBU utilization. When allocating baseband resources to RRHs in the BBU pool, the following constraints for matrix D are imposed.

- $\sum_{i=1}^M d_{ij} = 1$, that is, a single RRH cannot be connected to more than one BBUs at the same time.
- $\sum_{j=1}^N d_{ij} \cdot \delta_j^{RRH} \leq 1$, meaning for all RRHs connected to BBU_i , the total RRHs baseband demands should not be more than BBU_i normalized maximum capacity of 1.

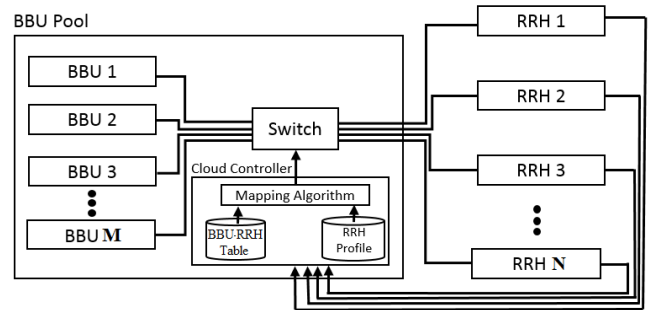


Fig. 3. iTREE system model structure.

The assumption for iTREE are as follows:

- All BBUs are homogeneous meaning they are of the same radio type with same capacity.
- BBUs are software defined hence a single BBU can process signals from multiple RRHs.

The algorithm for iTREE is shown in Fig. 4. The aim is to reduce the number of BBUs used and power off idle BBUs to save energy and reduce cost. This is done by dynamically allocating baseband processing resources to match traffic load. This means the number of BBUs will not always be equal to the number of RRHs as in conventional systems. In Step1, the upper bond BBU threshold ρ_{TH}^{BBU} is set. This is to prevent overloading of the BBU. The number of RRH is set to N . The variable M is initially set to N but will be minimised in the algorithm. The matrix $D_{M \times N}$ in step2 is then initialised where $\forall d_{ij} = 0$, that is, no RRH is connected to any BBU. Step3 loops all the BBUs in the pool in set B . Step4 loops within the RRHs in set R . In step5 RRH_j baseband resource demands δ_j^{RRH} is loaded into the algorithm from RRH-profile database. RRH_j need to be connected to a BBU with the largest utilization hence in step6, a BBU with the maximum utilization ρ_i^{BBU} is selected such that the sum of BBU_i utilization and RRH_j baseband resource demand does not exceed the maximum BBU threshold to avoid BBU overloading. Choosing a highly utilised BBU maximises utilization and ensure multiple RRH are served by a single BBU. The BBU utilization is then updated in step7 and also matrix D is updated by replacing $d_{ij} = 0$ with $d_{ij}=1$ showing that RRH_j is now connected to BBU_i . After the matrix D is updated, all the RRHs will be connected to their respective BBUs. In step11, any row i in matrix D summing up to at least more than one means that BBU_i is active and serving atleast one RRH. A total of such rows gives M , the total number of active BBUs in the BBU pool. If the BBU has no RRHs connected to it, the entire row i in matrix D sums to zero in

```

1: set  $\rho_{TH}^{BBU}, N, M \leftarrow N$ ;
2: set  $D \leftarrow (d_{ij})_{M \times N}; d_{ij} \leftarrow 0$ ;
3: for  $i = 1, i \leq M, i++$ ; //Row loop of BBU's
4:   for  $j = 1, j \leq N, j++$ ; //Column loop of RRH's
5:     get  $\delta_j^{RRH}$ ;
6:     find  $\rho_i^{BBU} \leftarrow \arg \max_{(\rho_i^{BBU})} (B: \rho_i^{BBU} + \delta_j^{RRH} \leq \rho_{TH}^{BBU})$ ;
7:      $\rho_i^{BBU} \leftarrow \rho_i^{BBU} + \delta_j^{RRH}$ ; // utilization update of  $BBU_i$ 
8:     update( $D$ ); //  $d_{ij} \leftarrow 1$ 
9:   end for
10: end for
11:  $M^* \leftarrow \text{count\_rows}(D) \text{ where } \sum_{j=0}^M d_{ij} \geq 1$ ; /ON BBU's
12: switch_Off BBU's where  $\sum_{j=0}^M d_{ij} = 0$ ; /idle BBU's
13: return ( $D, M^*$ );

```

Fig. 4. iTREE Bin Packing Algorithm for BBU-RRH mapping.

in step12. These are potential BBUs that can be switched off to save energy. The algorithm then output the minimum number of BBUs active M^* and the mapping matrix D which is stored in BBH-RRH table.

B. Power Model: Baseline

The BS system power model is derived from EARTH project [3]. It provides an accurate estimation of the BS power consumption considering different components of the radio equipment, such as antenna interface, power amplifier, baseband interface, cooling, etc. According to this model, the required BS input power consumption P_{in}^{BS} to attain a certain RF output power P_{out} can be computed as follows:

$$P_{in}^{BS} = P^{PA} + P^{RF} + P^{BBU}, P^{PA} = \frac{P_{out}}{\eta} \quad (1)$$

where P^{PA} , P^{RF} and P^{BBU} are power consumptions of power amplifier, RF, BBU respectively and η is efficiency of power amplifier. The baseline is conventional RAN with standalone BSs, where an area covered by N BSs consumes total power:

$$P_N^{BS} = N \cdot P_{in}^{BS} \quad (2)$$

This model cannot be directly used in C-RAN because multiple BBUs reside in the BBU pool and multiple RRHs can be served by a single BBU so the energy consumption of BBU per RRH should be reduced. As such a new power model for C-RAN is needed.

C. iTREE C-RAN Power Model

The C-RAN architecture achieves significant energy savings by consolidating several BBUs at the centralized server. Following the EARTH model component based methodology, we propose a traffic and computing resource aware power model for cloud BS based on EARTH model. The EARTH model is modified by splitting the RRH and BBU so as to compute power consumption at the BS-Cloud and the coverage area separately:

$$P_N^{C-RAN} = M \cdot P^{BBU} + N \cdot P^{RRH}, M \geq 1, N \geq 1 \quad (3)$$

$$P^{RRH} = P^{PA} + P^{RF} \quad (4)$$

where P_N^{C-RAN} is the total power in a C-RAN network of N RRHs. P^{RRH} is power consumptions of a single RRH. The $M \cdot P^{BBU}$ term denote the power consumption in the BBU pool after reducing the number of BBUs to M . The $N \cdot P^{RRH}$ term calculate the overall power consumption in the coverage area side covered by N RRHs. The value of N is known from the number of RRHs in coverage area. To evaluate M , it is imperative to get the normalised traffic load $\delta_j^{RRH} \in [0,1]$ from each RRHs which correspond to baseband resource demands. A single BBU has maximum processing resources of $\rho_{max}^{BBU} = 1$. A BBU threshold value ρ_{TH}^{BBU} is also considered to avoid overloading of BBUs. The value M is the number of

BBUs that are active with utilization greater than zero as derived from the BBU-RRH mapping algorithm in Fig. 4. This value of M is equivalent to a novel approach below:

$$M = \left\lceil \frac{1}{\rho_{TH}^{BBU}} \sum_{j=1}^N \delta_j^{RRH} \right\rceil, \quad \rho_{TH}^{BBU} < 1, \delta_j^{RRH} \in [0,1] \quad (5)$$

The traffic load in the RRH is assumed as the baseband processing resource demand for the RRH. All variables are enclosed on the ceil function in equation (5) to roundup M to the nearest upper integer so that all RRHs baseband signals are processed without BBU shortage. The sigma function sums the total baseband processing demands so as to evaluate how many BBU are required to serve the RRH demand aggregate. To prevent BBU overloading, it is imperative to set upper BBU utilization limit ρ_{TH}^{BBU} to ensure additional headroom of $1 - \rho_{TH}^{BBU}$ in BBU. Fig. 5 shows an example of how the values of M and D are evaluated given three RRHs, RRH resource demands and BBU utilizations.

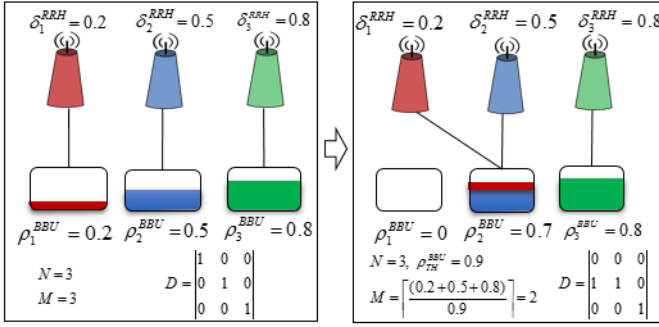


Fig. 5. An example of evaluating M and D in a 3 RRH RAN network.

Using equation (5), the number of BBUs M_{OFF}^{BBU} that can be switched off are calculated as follows:

$$M_{OFF}^{BBU} = N - \left\lceil \frac{1}{\rho_{TH}^{BBU}} \sum_{j=1}^{j=N} \delta_j^{RRH} \right\rceil \quad (6)$$

One way of estimating the value of M is to use the average baseband resource demand δ_{mean}^{RRH} in the whole network. Hence, M becomes:

$$M_{mean} \approx \begin{cases} \left\lceil \frac{N \cdot \delta_{mean}^{RRH}}{\rho_{TH}^{BBU}} \right\rceil, & \delta_{mean}^{RRH} < 5 \\ N, & \delta_{mean}^{RRH} \geq 5 \end{cases} \quad (7)$$

Substituting equation (5) into (3), the total power consumed in C-RAN with N number of RRHs:

$$P_N^{CRAN} = \left\lceil \frac{1}{\rho_{TH}^{BBU}} \sum_{j=1}^N \delta_j^{RRH} \right\rceil \cdot P^{BBU} + N \cdot P^{RRH} \quad (8)$$

V. SIMULATION AND RESULTS

A. Simulation Parameters

A coverage area of 100 RRHs is considered, i.e. $N=100$. The proposed iTREE scheme is compared with a baseline conventional cell deployment from EARTH [3] where each RRH is served by its own BBU such that 100 BBUs are always in use. Equation (2) is used to evaluate the power consumption of baseline. iTREE is also compared with a C-RAN based BBU-RRH Optimum switching scheme by S. Namba *et al.* in [11] which is called Namba-Optimum. The Namba-Optimum scheme also aims to reduce the number of BBUs though dynamic BBU provisioning. The BBU maximum threshold is set to 0.9 which is the mostly adapted threshold in most literature like in [11]. For the RRH traffic load, two typical traffic profiles from [11] are used. One is for residential area as shown in Fig. 6, another one is for office/business area as shown in Fig. 7. The BBU-RRH switching scheme is in intervals of one hour. The target time is 24 hours. TABLE I shows power consumption parameters of LTE RRH BS from EARTH to be used.

TABLE I. LTE RRH BS POWER CONSUMPTION PARAMETERS [3]

| P_{out} [dBm] | η [%] | P^{RF} [W] | P^{BBU} [W] |
|-----------------|------------|--------------|---------------|
| 43 | 31.1 | 13 | 29.5 |

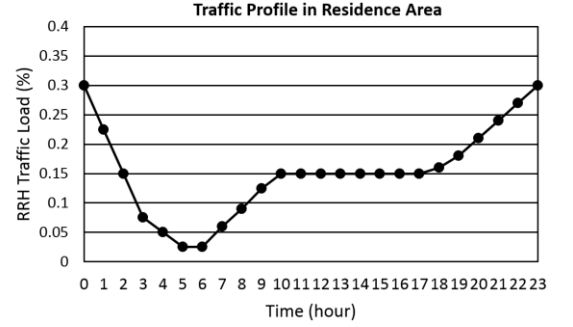


Fig. 6. Traffic profile in residence area.

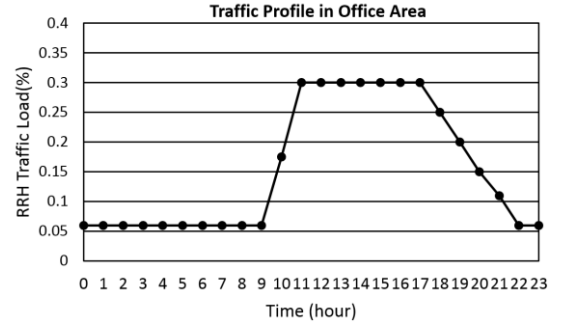


Fig. 7. Traffic profile in office area.

B. Results and Analysis

a) BBU Reduction

BBU reduction in residence area: Fig. 8 shows the number of BBUs allocated to 100 RRHs for a duration of 24 hours in a residential area. 100 BBUs are statically assigned to 100 RRHs in the conventional baseline scheme. This leads to low utilization of BBUs. On the other hand, the number of BBUs assigned by Namba-Optimum and iTREE are adaptive and changes according to traffic load. For both adaptive schemes, a more BBUs are assigned during high traffic loads than during low traffic periods.

As shown in Fig. 6, during low traffic times (0500-0600), iTREE reduces BBU assigned by 97% compared to Namba-Optimum scheme that reduces the BBUs by 95%. During the 24 hour period, the average number of BBU utilised in iTREE and Namba-Optimum is 17 and 23 respectively corresponding to 83% and 77% BBU reductions. During high traffic loads (2300-0000), iTREE performs much better than Namba-Optimum reducing assigned BBUs by 66% while Namba-Optimum reduce BBUs by 52%.

BBU reduction in office area: Fig. 9 shows the number of BBUs allocated in an office area. An office area has busy traffic during the day but less traffic during the night. During off peak times (2200-0900), both schemes reduces the allocated BBUs by 94%. During peak hours (1100-1700), iTREE reduces the BBUs by 66% while Namba-Optimum lags behind at 55%. iTREE performs much better during peak times for both residential and office areas.

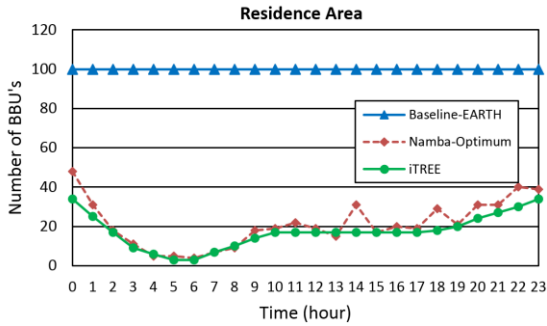


Fig. 8. Number of assigned BBUs in residence area.

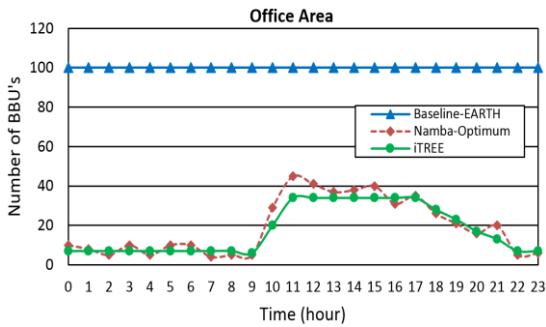


Fig. 9. Number of assigned BBUs in office area.

b) Power Consumption

Power consumption in residence area: Fig. 10 shows the power consumption of 100 RRH RAN network in residence areas. Using equation (2) where $N=100$, the baseline-EARTH scheme consume a constant power of 10681W during both high and low traffic since 100 BBUs are always used to serve individual RRHs. iTREE consumes 7819W during low traffic since only 3 BBUs are used. However, Namba-Optimum scheme consume 7878W with 5 BBUs utilized. Therefore iTREE reduces power consumption in network by 27% as compared to 26% from Namba-Optimum scheme. During high traffic load, iTREE uses 34 BBUs leading to 8734W consumption with 18% power reduction while Namba-Optimum scheme uses 48 BBUs with 9147W consumption at 14% power reduction. The average daily power consumptions for iTREE and Namba-Optimum are 8243W and 8357W at 23% and 22% power reduction respectively.

Power consumption in office area: The power consumption in office area is shown in Fig. 11. For low traffic, Both iTREE and Namba Optimum consume 7908W (6 BBUs) with 26% power reduction, but during peak loads, iTREE consume 8734W (34 BBUs) while Namba-Optimum scheme consume 9058W (45 BBUs) at 18% and 15% respectively. The average daily power consumptions for iTREE and Namba-Optimum are 8250W and 8315W at 23% and 22% power reduction respectively. As such for both office and residential areas, the average power consumption is the same.

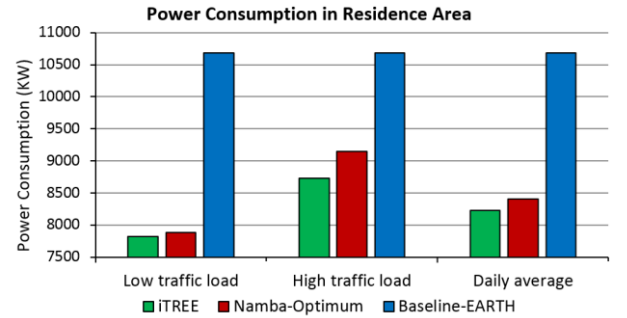


Fig. 10. Power consumption in residence area.

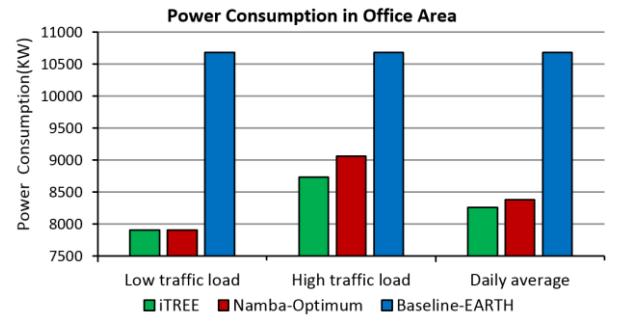


Fig. 11. Power consumption in office area.

VI. CONCLUSION AND FUTURE WORK

This paper presents iTREE scheme that reduces the number of BBUs in C-RAN that can serve a large number of RRHs while not affecting the coverage area. Conventional BSs have been preconfigured to provide peak load but rarely at its peak in practical scenarios, as such a lot of BBUs are underutilised while at the same time consuming a lot of power. A power model for C-RAN was proposed with promising savings. Simulation results show that iTREE can reduce BBUs by up to 97% during off peak and 66% at peak loads with network power reductions of up to 27% and 18% respectively compared with conventional deployments from the EARTH power scheme.

iTREE scheme will be extended using Real Time (RT) virtualization on General Purpose Processors (GPPs) so that further energy saving are gained. The BBU reduction scheme is an NP hard problem and will be further optimized using effective multi-dimensional bin packing algorithm taking into consideration both computing and spectrum resources.

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